

DESCRIPTION

SILANE COUPLING AGENT TREATED-SILICA AND
RUBBER COMPOSITION CONTAINING THE SAME

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TECHNICAL FIELD

The present invention relates to a silane coupling agent-treated silica and a rubber composition containing the same, more specifically relates to a silane coupling agent- (or an organic silane compound-) surface-treated silica capable of suppressing reactions involving the silane coupling agent at the time of compounding, without detracting from the reinforcing capability, improving the dispersibility of the silica, and improving the abrasion resistance, wet skid performance, etc. in a rubber composition containing silica and a rubber composition containing the same.

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BACKGROUND ART

In recent years, in tread compounds for passenger car tires, it becomes the practice to compound silica in the compounds in order to reduce the fuel consumption due to the tires and improve the wet skid performance. For improving the reinforcing capability or processability of the silica-containing rubber composition, a silane coupling agent having, in the molecule thereof, an alkoxysilyl group capable of chemically reacting with silica, typically Si69 commercially available from Degussa is used. However, this silica-containing rubber composition is accompanied with a reaction between the silane coupling agent and silica or a reaction between silica and the polymer through the silane coupling agent at the time of mixing etc. These reactions form alcohol, whereby the generation of porosity is caused or the control of the mixing temperature (for example, 140 to 165°C) is required, and therefore there was the problem that they unpreferably decrease the productivity. For this reason, it has been proposed not to add a silane

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coupling agent to the rubber composition, but to pretreat the silica with a silane coupling agent (see, for example, U.S. Patent No. 4141751, EP-A-177674, JP-A-59-206469, JP-A-5-17705, JP-A-9-328631 and JP-A-2002-3652).

5 However, for this sort of pre-treated silica, if the amount of the silane coupling agent used for the pre-treatment is increased, the problem remains that the reaction between the silane coupling agents causes the silica to aggregate and the viscosity of the rubber
10 composition to increase.

However, to secure drivability, braking capability, driving stability and other ice performance of studless tires on ice or snow covered roads, in the past, from the viewpoint of improvement of the rubber quality, the
15 practice has been to compound a rubber having a low glass transition temperature such as butadiene rubber into a rubber composition containing natural rubber, to increase the amount of softener to be compounded, or to compound a silica-based filler, short fiber, porous substance, etc.
20 so as to improve the quality of hard-to-cure rubber even at low temperatures, but the abrasion resistance, driving stability, etc. are decreased and, therefore, a satisfactory result cannot be obtained just by the improvement in the low temperature characteristics of the
25 rubber.

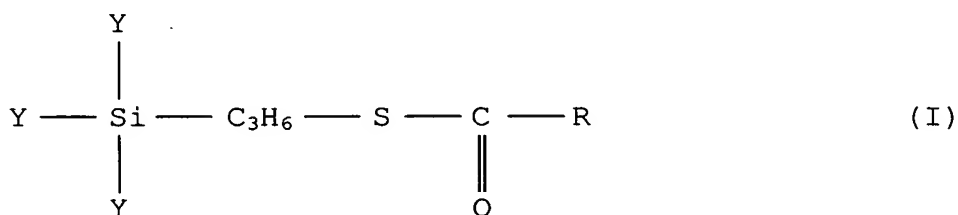
SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is to provide a surface-treated silica for a rubber composition capable of avoiding the problems of a silica-
30 containing rubber composition due to the silane coupling agent and capable of improving the processability, silica dispersibility, abrasion resistance, wet braking performance, etc. and a rubber composition containing the same.

35 Another object of the present invention is to provide a rubber composition capable of avoiding the problems due to silica and a silane coupling agent in a

natural rubber (NR)/polybutadiene rubber (BR) and capable of improving the low temperature characteristics such as frictional force on ice, without detracting from the processability, abrasion resistance, aging resistance and driving stability.

In accordance with the present invention, there is provided a surface-treated silica treated, on the surface thereof, with at least silane coupling agent X represented by the formula (I):



wherein Y independently indicates a methoxy, ethoxy, propoxy, isopropoxy, butoxy, isobutoxy or acetoxy group, R indicates a C₁ to C₁₈ hydrocarbon group selected from a linear, cyclic, or branched alkyl group, alkenyl group, aryl group, and aralkyl group.

In accordance with the present invention, there is also provided the silica treated, on the surface thereof, with a silane coupling agent, where the surface-treated silica treated on the surface thereof, with the silane coupling agent X has a bulk density retention rate of 50 to 150%.

In accordance with the present invention, there is further provided a rubber composition comprising a rubber component containing 100 parts by weight of at least one a diene-based rubber and silica treated, on the surface thereof in advance, with 2 to 100 parts by weight particularly 20 to 100 parts by weight of the silane coupling agent X.

In accordance with the present invention, there is still further provided a rubber composition for a studless tire comprising 30 to 80 parts by weight of

natural rubber, 70 to 20 parts by weight of polybutadiene rubber and 2 to 30 parts by weight of silica treated, on the surface thereof, with at least one silane coupling agent X having the above formula (I).

5 BEST MODE FOR CARRYING OUT THE INVENTION

 The present inventors found that, for example, by compounding silica treated, on the surface thereof, with 3-octanoylthio-propyltrialkoxysilane having, at one end thereof, a trialkoxysilyl group reactive with silica, it
10 is possible to suppress the reaction between silane coupling agents with each other, without impairing the reinforcing capability, so as to improve the dispersibility of silica and to thereby keep the Mooney viscosity of the rubber composition low and to obtain a
15 rubber composition having a small dependency of the Mooney viscosity on the mixing temperature and that further by using this rubber composition, a pneumatic tire having superior abrasion resistance, wet skid performance, etc. can be obtained.

20 The singular forms ("a", "an", and "the") used in the present description and the attached claims should be understood as including the plural form except when otherwise clear from the context.

 As the rubber composition compounded into the rubber
25 composition according to the first aspect of the present invention, any diene-based rubber generally used in the past for tires or other applications, for example, various types of natural rubber (NR), various types of polyisoprene rubber (IR), various types of styrene-
30 butadiene copolymer rubber (SBR), various types of polybutadiene rubber (BR), various types of acrylonitrile-butadiene copolymer rubber (NBR), etc. may be mentioned. These may be used alone or in any blends thereof. In the rubber composition according to the
35 present invention, the rubber component contains natural rubber (NR) in an amount of preferably 10% by weight or more, more preferably 15 to 80% by weight, and styrene-

butadiene copolymer rubber (SBR) in an amount of preferably 20% by weight or more, more preferably 20 to 85% by weight, and further, optionally, any other diene-based rubber, where the temperature dependency of the rubber physical properties such as dynamic elasticity E' becomes smaller and the wet skid performance in a broad temperature range, in particular the low temperature range, is further improved.

In the second aspect of the present invention, by compounding silica treated, on the surface thereof, with silane coupling agent X such as 3-octanoylthiopropyltriethoxysilane or into an NR/BR system, the inventors succeeded in realizing both abrasion resistance and performance on ice. In particular, the abrasion resistance and temperature dependency of the hardness are small, the performance on ice is superior in all temperature regions, the molecular chain cleavage of the polymer at the time of mixture is small, the change in hardness due to aging is small, and the Mooney viscosity is reduced.

As the rubber component compounded into the rubber composition according to the second aspect of the present invention, natural rubber (NR) and polybutadiene rubber (BR) are used in a ratio NR/BR of 30 to 80/70 to 20 (parts by weight), preferably 40 to 70/60 to 30 (parts by weight). If the ratio of NR in this formulation is too large, the abrasion resistance and the frictional force on ice at the time of a low temperature are decreased, and therefore this is not preferable. Conversely, if too small, the strength of the rubber is decreased, and therefore this is not preferable. Note that, as the natural rubber, any natural rubber usable in the rubber industry in the past can be used. The same is true for polybutadiene rubber. Note that, as the natural rubber or polybutadiene rubber, a polybutadiene rubber having a glass transition temperature of -55°C or less is preferable.

As the silica usable in the present invention, any silica usable for a tire in the past, for example, natural silica, synthetic silica, more specifically precipitated silica, dry silica or wet silica may be used. According to the present invention, the silica is used uniformly mixed with and treated, on the surface thereof, with the silane coupling agent X having the formula (I). This surface treatment is based on the chemical or physical bonding such as the reaction of the silica and the trialkoxysilyl group ($-\text{SiY}_3$) of the silane coupling agent X having the formula (I). Note that the silane coupling agent may be used for treatment of the surface of the silica after the pre-treatment such as hydrolysis, condensation. Further, to complete the reaction between the silica and silane coupling agent, it is also possible to use the method of hydrolyzing and condensing the silane coupling agent in advance before reaction with the silica, the method for aging by heating, the method for adding a reaction accelerator such as a catalyst (for example, acid-alkali-tin/aluminum or other organometallic catalyst).

As the silane coupling agent X usable in the present invention, for example, 3-octanoylthiopropyltriethoxysilane, 3-propionitrylthiopropyltrimethoxysilane, etc. may be mentioned. These may be synthesized by a known method. Specifically, the method disclosed in JP-A-2001-505225 (rubber containing filler) enables them to be obtained by a reaction between the corresponding mercaptosilane and acid anhydride or acid chloride or ester exchange reaction between the corresponding mercaptosilane and thioester. Note that 3-octanoylthiopropyltriethoxysilane is commercially available from Nippon Unicar K.K. as NXT Silane.

Silica particles may be treated on their surface by a known method, for example, the dry reaction method, wet reaction method, etc. The dry reaction method is a method

for charging silica particles into a Henschel mixer or other high speed agitation apparatus and agitating them, while adding the silane coupling agent X or a hydrolyzed solution of the silane coupling agent X. As the method
5 for addition, the method of uniform reaction of the silane coupling agent X is preferable. A known method, for example, the method of gradual dropping, the method of spraying in a mist, the method of introducing a gaseous silane, etc. may be used. The wet reaction method
10 is the method for dispersing silica particles in a solution of silane coupling agent, causing a reaction in that state, and then optionally drying. As the solvent used, water, alcohol, or a mixture of the same are preferable. In either of the dry reaction method and wet
15 reaction method, a known method for increasing the reactivity of the silane coupling agent and the hydroxy groups on the surface of the silica particles, for example, the method of post heat treatment or the method of using a condensation catalyst such as an acid, alkali,
20 organometal (for example, a tin- or aluminum-based organometal) may be used.

In the present invention, the bulk density retention rate of the silica treated on the surface thereof with the silane coupling agent X is preferably 50 to 150%,
25 more preferably 60 to 140%. Here, the "bulk density retention rate (%)" means the value derived from the following equation (II).

[(Bulk density of silica after surface treatment -
30 bulk density of silica after surface treatment)/(Bulk density of silica before surface treatment x silane coupling agent treatment rate/100)] x 100 (II)

35 Here, the "silane coupling agent treatment rate (%)" means the ratio of the silane coupling agent used for treatment of the surface of the silica and is the value

derived from the following formula:

$$\left[\frac{\text{Weight of silane coupling agent}}{\text{Weight of silica before treatment}} \right] \times 100$$

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10 If the bulk density retention rate is too small, a sufficient amount of surface treatment cannot be obtained, and, therefore, the desired effect is liable to be hard to obtain. Conversely, if too large, the surface treatment cannot be performed uniformly and the dispersibility in the rubber or processability are liable to become insufficient, and, therefore, this is not preferable. Note that the bulk density was measured, based on the method of JIS K 5101, and evaluated by three test samples randomly sampled from the surface-treated silica.

15 The silica treated on the surface thereof with the silane coupling agent X used in the present invention is compounded into 100 parts by weight of a rubber component in an amount of 2 to 100 parts by weight, preferably 5 to 100 parts by weight. If the amount is too small, the wet skid performance is decreased, and, therefore, this is not preferable, while conversely if too large, the dispersibility of silica deteriorates and the abrasion resistance is decreased, and, therefore, this is not preferable. The silane coupling agent treatment rate of the silica and silane coupling agent X according to the present invention is not particularly limited, but 1 to 25% is preferable, and 4 to 25% is more preferable.

20 25 30 35 In the rubber composition according to the first aspect of the present invention, the silica treated with the silane coupling agent is preferably included in 100 parts by weight of the rubber component in an amount of 20 to 100 parts by weight, more preferably 30 to 100 parts by weight.

In the rubber composition according to the second aspect of the present invention, from the viewpoint of

the frictional force on ice or abrasion resistance, the silica treated with the silane coupling agent is preferably included in 100 parts by weight of the rubber component in an amount of 2 to 30 parts by weight, more preferably 5 to 25 parts by weight.

The rubber composition according to the present invention may further contain, in addition to the above essential ingredients, carbon black or another filler, vulcanization or cross-linking agent, vulcanization or cross-linking accelerator, various types of oil, antioxidant, plasticizer, or other various types of additives generally compounded for tire use or other general rubber uses. The additives may be mixed and vulcanized to obtain a composition by a general method and used for vulcanization or cross-linking. The amounts of these additives may be made the conventional general amounts so long as not running counter to the present invention.

EXAMPLES

Examples will now be used to explain the present invention further, but the present invention is not limited to these Examples.

Standard Example 1, Examples 1 to 5 and Comparative Examples 1 to 4

Preparation of Samples

In each of the formulations shown in Table I, the ingredients other than the vulcanization accelerator and sulfur were mixed in a 3 liter internal mixer for 5 minutes and discharged, when reaching $165 \pm 5^\circ\text{C}$, to obtain a master batch. This master batch was mixed with the vulcanization accelerator and sulfur by an open roll to obtain a rubber composition. This rubber composition was used to evaluate the unvulcanized physical properties by the following test methods. The results are shown in Table I.

Next, the rubber composition thus obtained was vulcanized in a 15 x 15 x 0.2 cm mold at 160°C for 30

minutes to prepare a vulcanized rubber sheet which was then measured for the physical properties of the vulcanized rubber by the following test methods. The results are shown in Table I.

5 Test Methods for Evaluation of Rubber Physical Properties

Mooney viscosity (ML_{1+4}): Measured based on JIS K-6300 mixed at 130°C, 160°C, and 180°C.

10 Payne effect: E' and E'' were measured under conditions of a frequency of 20 Hz, an initial strain of 10% and an amplitude of 0.08 to 10%, $E'(0)$ and $E'(\infty)$ found from a cole-cole plot, and $E'(0) - E'(\infty)$ calculated. The smaller the value of $E'(0) - E'(\infty)$ the better the dispersibility of the filler shown.

15 Abrasion resistance: A Lambourn abrasion tester was used to measure the volume of abrasion loss under conditions of a temperature of 23°C/slip rate 50%. In Table I, the value is shown indexed to Standard Example 1 and in the later Table II, the value is shown indexed to
20 Standard Example 2. The larger this value, the better the abrasion resistance shown.

25 M300/M100: The 300% modulus (M300) and 100% modulus (M100) were measured according to JIS K-6251. Note that the larger the value of M300/M100, the better the reinforcing action shown.

30 Wet skid performance: The $\tan\delta$ at 0°C was measured under conditions of a frequency of 20 Hz, an initial strain of 10% and an amplitude of $\pm 2\%$. The value of $\tan\delta$ (0°C) at this time is correlated with the wet skid resistance. The larger the value, the better the wet skid resistance shown.

Table I

Formulation (parts by weight)	Stand.		Comp.		Comp.		Comp.		Ex.		Ex.		Ex.		Ex.		Ex.	
	Ex. 1	Ex. 1	Ex. 1	Ex. 2	Ex. 2	Ex. 3	Ex. 4	Ex. 4	Ex. 1	Ex. 2	Ex. 3	Ex. 4	Ex. 5	Ex. 1	Ex. 2	Ex. 3	Ex. 4	Ex. 5
SBR	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
BR	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Silica	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
A-1289	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6
A-1589	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NXT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A-1289 treated silica (8% ^{*1}) (75 to 82% ^{*4})	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A-1589 treated silica (8% ^{*1}) (85 to 90% ^{*4})	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NXT treated silica (5% ^{*2}) (95 to 99% ^{*4})	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NXT treated silica (11% ^{*2}) (96 to 98% ^{*4})	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NXT treated silica (20% ^{*2}) (75 to 82% ^{*4})	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NXT treated silica (2% ^{*2}) (95 to 98% ^{*4})	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NXT treated silica (30% ^{*2}) (90 to 105% ^{*4})	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CB	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
6C	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
RD	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Zinc White	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Stearic acid	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Oil	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
CZ	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
DPG	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Sulfur	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
<u>Evaluation of physical properties</u>																		
Mooney viscosity (130°C ^{*3})	100	103	110	110	90	91	91	91	80	75	65	60	85	80	75	65	60	85
Mooney viscosity (160°C ^{*3})	100	105	105	105	87	85	85	85	85	80	74	70	86	85	80	74	70	86
Mooney viscosity (180°C ^{*3})	100	92	90	90	98	94	94	94	88	83	75	73	89	88	83	75	73	89
Payne effect (160°C ^{*3})	100	84	81	81	106	84	84	84	75	60	51	65	83	75	60	51	65	83
Abrasion resistance (160°C ^{*3})	100	90	100	100	101	94	94	94	110	120	140	130	115	110	120	140	130	115
M300/M100 (160°C ^{*3})	100	95	94	94	100	90	90	90	100	100	103	101	101	100	100	103	101	101
Wet skid performance (160°C ^{*3})	100	95	98	98	105	97	97	97	105	110	115	112	107	105	110	115	112	107

*1: Silane coupling agent treatment rate by A-1289 or A-1589

*2: Silane coupling agent treatment rate by NXT silane

*3: Mixture temperature of silica before silane coupling agent or silane coupling agent treatment

*4: Bulk density retention rate

Notes to Table I

SBR: Nipol 1502 made by Nippon Zeon

BR: Nipol BR 1220 made by Nippon Zeon

Silica: Nipsil AQ made by Toso Silica Industry

5 A-1289: Bis(3-triethoxysilylpropyl)tetrasulfane made by Nippon Unicar

A-1589: Bis(3-triethoxysilylpropyl)disulfane made by Nippon Unicar

10 NXT: 3-octanoylthiopropyltriethoxysilane (NXT Silane) made by Nippon Unicar

A-1289 surface-treated silica and A-1589 surface treated silica: Nippon Unicar NUCA-1289 silane or NUCA-1589 was slowly added in Henschel mixer into Nipsil AQ (Toso Silica Industry) while stirring to prepare dry reaction
15 silica particles. The silane coupling agent reaction silica particles were dried in an explosion-proof oven set to 150°C for 1 hour.

NXT treated silica: 3-octanoylthiopropyl-triethoxysilane (NXT Silane) was slowly added by a Henschel mixer into
20 Nipsil AQ (Toso Silica Industry) while stirring to prepare dry reaction silica particles. The silane coupling agent reaction silica particles were dried in an explosion-proof oven set to 150°C for 1 hour. Note that the bulk density retention rate was found in the above
25 way. The results are shown in Table I.

CB: Shoblack N339 made by Showa Cabot

6C: Santoflex 6PPD made by Flexsys

RD: Nocrac 224 made by Ouchi Shinko Chemical Industrial

Zinc White: Ginrei R made by Toa Zinc

30 Stearic acid: Beads Stearic Acid YR made by NOF Corporation

Oil: Process X-140 made by Japan Energy

CZ: Noccelar CZ-G made by Ouchi Shinko Chemical Industrial

35 DPG: Soxinol D-G made by Sumitomo Chemical

Sulfur: Oil extended sulfur made by Karuizawa Refinery (oil content 5%)

As is clear from the results shown in Table I, in Examples 1 to 5, compared with the Standard Example 1, the decrease in the Mooney viscosity was large, the dependency on the mixing temperature was small, and further the abrasion resistance, M300/M100 (reinforcing action), and wet braking performance were good and the Payne effect was decreased. As opposed to this, in Comparative Examples 1 to 2, the A-1589 and 3-octanoylthiopropyl-triethoxysilane were charged into solutions, so the viscosity was higher than the A-1289 formulation. However, with mixing at 180°C, the viscosity was decreased. This is believed because the amount of sulfur contained in the coupling agent is small, so no rubber scorching occurs. Further, in Comparative Examples 3 and 4, silica treated in advance by A-1289 and A-1589 were contained, and therefore the decrease in the viscosity was larger than with charging in a solution. Compared with Comparative Examples 1 and 2, the abrasion resistance, M300/M100 (reinforcing action) and wet skid performance were also improved.

Standard Example 2, Examples 6 to 7, and Comparative Example 5

Preparation of Samples

In each of the formulations shown in Table II, the ingredients other than the vulcanization accelerator and sulfur were mixed in a 3 liter internal mixer for 5 minutes and discharged when reaching 165±5°C to obtain a master batch. This master batch was mixed with the vulcanization accelerator and sulfur by an open roll to obtain a rubber composition. This rubber composition was used to evaluate the unvulcanized physical properties by the above test methods. The results are shown in Table II.

Next, the rubber composition thus obtained was vulcanized in a 15 x 15 x 0.2 cm mold at 160°C for 30

minutes to prepare a vulcanized rubber sheet which was then measured for the physical properties of the vulcanized rubber by the above test methods. The results are shown in Table II.

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Table II

	Stand. Ex. 2	Comp. Ex. 5	Ex. 6	Ex. 7
<u>Formulation (parts by weight)</u>				
SBR ^{*1}	80	80	80	80
BR ^{*1}	20	20	20	20
silica ^{*1}	70	70	70	70
CB ^{*1}	10	10	10	10
6C ^{*1}	2	2	2	2
RD ^{*1}	2	2	2	2
Zinc White ^{*1}	2	2	2	2
Stearic acid ^{*1}	1	1	1	1
Oil ^{*1}	10	10	10	10
CZ ^{*1}	2.2	2.2	2.2	2.2
DPG ^{*1}	0.2	0.2	0.2	0.2
Sulfur ^{*1}	1.6	1.6	1.6	1.6
A-1289 ^{*1}	-	Treatment method 2	-	-
NXT ^{*1}	Treatment method 1	-	Treatment method 2	Treatment method 3
Bulk density retention rate (%)	23.5 to 170	75 to 82	95 to 98	96 to 99
<u>Evaluation of physical properties</u>				
Mooney viscosity (130°C) ^{*1}	100	95	68	66
Mooney viscosity (160°C) ^{*1}	100	85	73	71
Mooney viscosity (180°C) ^{*1}	100	103	79	75
Payne effect ^{*1}	100	106	51	48
Abrasion resistance ^{*1}	100	103	143	144
M300/M100 ^{*1}	100	100	103	104
Wet skid performance ^{*1}	100	104	114	115

Notes to Table II

*1: See notes to Table I

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Standard Example 2: 300 g of Nipsil AQ (Toso Silica Industry) was taken into a stainless steel bowl. 30 g of 3-octanoylthiopropyltriethoxysilane was added, then a stainless steel spatula was used for stirring for 5 minutes to prepare treated silica, then the bulk density

retention rate was measured. First, test samples of 20 g amounts were randomly selected from three groups of the treated silica were taken. The first sample was passed through a 0.50 mm sieve to be received by a 30.0 ml stainless steel cylinder. When the silica passed into the silica formed a pile, it was taken out by a straight spatula. The weight inside the cylinder was measured and found to be 7.369 g. The following formula was used to find the bulk density:

$$\text{Bulk } 0.24563 \text{ (g/ml)} \cong 7.369 \text{ (g)} / 30 \text{ (ml)}$$

Since the bulk density of the silica used for the treatment was 0.240 g/ml, the bulk density retention rate was found by the following formula:

$$[(0.24563 - 0.240) / (0.240 \times 0.10)] \times 100 = 23.5 \text{ (\%)}$$

The same procedure was followed to measure the remaining sample, whereupon the values obtained were 170% and 50.8%. It was confirmed that the range of the bulk density retention rate was 23.5% to 170%. (Treatment method 1)

Comparative Example 5: 30 g of NUCA-1289 silane made by Nippon Unicar was slowly added by a Henschel mixer into 300 g of Nipsil AQ (Toso Silica Industry), while stirring, to prepare dry surface-treated silica particles. The silane coupling agent surface-treated silica particles were dried in an explosion-proof oven set to 150°C for 1 hour. The same method as in Standard Example 2 was used to measure the range of the bulk density retention rate. It was confirmed to be 75 to 82%. (Treatment method 2)

Example 6: 30 g of 3-octanoylthiopropyl-triethoxysilane (NXT Silane) was slowly added by a Henschel mixer into 300 g of Nipsil AQ (Toso Silica Industry), while stirring, to prepare dry surface treated

silica particles. The silane coupling agent-surface-treated silica particles were dried in an explosion-proof oven set to 150°C for 1 hour. The same method as in Standard Example 2 was used to measure the range of the bulk density retention rate. It was confirmed to be 95 to 98%. (Treatment method 2)

Example 7: Except for not drying in an explosion-proof oven, the same procedure was followed as in Example 6 for treatment. The same method as with Standard Example 2 was used to measure the range of the bulk density retention rate. It was confirmed to be 96 to 99%. (Treatment method 3)

Standard Example 3, Examples 8 to 12, and Comparative Examples 6 to 9

Preparation of Samples

In each of the formulations of Table III, the ingredients other than the vulcanization accelerator and sulfur were mixed in a 3 liter internal mixer for 5 minutes and discharged, when reaching 165±5°C to obtain a master batch. This master batch was mixed with the vulcanization accelerator and sulfur by an open roll to obtain a rubber composition. This rubber composition was used to evaluate its unvulcanized physical properties by the above-mentioned test method. The results are shown in Table III.

Next, the rubber composition thus obtained was vulcanized in a 15 x 15 x 0.2 cm mold at 160°C for 30 minutes to prepare a vulcanized rubber sheet, which was then measured for the physical properties of the vulcanized rubber by the above test methods except for the $\Delta E'$ (E' temperature dependency) and low temperature wet skid performance. The results are shown in Table III.

Table III

	Stand. Ex. 3	Comp. Ex. 6	Comp. Ex. 7	Comp. Ex. 8	Comp. Ex. 9	Ex. 8	Ex. 9	Ex. 10	Ex. 11	Ex. 12
<u>Formulation (parts by weight)</u>										
SBR ²	80	80	80	80	80	80	80	80	80	80
NR ³	20	20	20	20	20	20	20	20	20	20
Silica ^{*1}	70	70	70	-	-	-	-	-	-	-
A-1289 ^{*1}	5.6	-	-	-	-	-	-	-	-	-
A-1589 ^{*1}	-	5.6	-	-	-	-	-	-	-	-
NXT ^{*1}	-	-	7.7	-	-	-	-	-	-	-
A-1289 treated silica (8% ^{*1})	-	-	-	75.6	-	-	-	-	-	-
A-1589 treated silica (8% ^{*1})	-	-	-	-	75.6	-	-	-	-	-
NXT treated silica (5% ^{*1})	-	-	-	-	-	73.5	-	-	-	-
NXT treated silica (11% ^{*1})	-	-	-	-	-	-	77.7	-	-	-
NXT treated silica (20% ^{*1})	-	-	-	-	-	-	-	84	-	-
NXT treated silica (2% ^{*1})	-	-	-	-	-	71.4	-	-	-	-
NXT treated silica (30% ^{*1})	-	-	-	-	-	-	-	-	-	91
CB ^{*1}	10	10	10	10	10	10	10	10	10	10
6C ^{*1}	2	2	2	2	2	2	2	2	2	2
RD ^{*1}	2	2	2	2	2	2	2	2	2	2
Zinc White ^{*1}	2	2	2	2	2	2	2	2	2	2
Stearic acid ^{*1}	1	1	1	1	1	1	1	1	1	1
Oil ^{*1}	10	10	10	10	10	10	10	10	10	10
CZ ^{*1}	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
DPG ^{*1}	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Sulfur ^{*1}	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
<u>Evaluation of physical properties</u>										
Mooney viscosity (130°C)	100	103	110	90	91	80	75	65	60	85
Mooney viscosity (160°C)	100	105	105	87	85	85	80	74	70	90
Mooney viscosity (180°C)	100	92	90	98	94	88	83	75	73	90
Payne effect (160°C ^{*3})	100	84	81	106	84	75	65	60	70	78
Abrasion resistance (160°C ^{*3})	100	90	100	101	94	105	115	130	120	112
ΔE'	100	92	75	90	95	73	70	67	65	73
Low temperature wet skid performance	100	95	98	105	97	105	110	115	112	107

(Note) For values of bulk density retention rate of treated silica, see Table I.

Notes to Table III

*1: See notes to Table I

*2: Nipol 1502 made by Nippon Zeon

*3: Natural rubber (TSR20)

5 $\Delta E'$: Difference in E' at -20°C and 20°C (dynamic elasticity) indexed against value of Standard Example 3 (Table III) or Standard Example 4 (Table IV). The smaller the value, the smaller the temperature dependency of E' shown.

10 Low temperature wet skid performance: A British Standard Portable Skid Tester (made by Stanley London) was used to measure the performance under conditions of a wet road surface (water temperature 8°C). The results were indexed to Standard Example 3. The larger the value, the better
15 the low temperature wet skid performance shown.

Standard Example 4, Examples 13 to 14, and
Comparative Example 10

Preparation of Samples

20 In each of the formulations shown in Table IV, the ingredients other than the vulcanization accelerator and sulfur were mixed by a 3 liter internal mixer and discharged, when reaching $165\pm 5^{\circ}\text{C}$, to obtain a master batch. This master batch then had the vulcanization
25 accelerator and sulfur kneaded into it by an open roll to obtain a rubber composition. This rubber composition was used and evaluated by the above test method for the unvulcanized physical properties. The results are shown in Table IV.

30 Next, each rubber composition thus obtained was vulcanized in a $15 \times 15 \times 0.2$ cm mold at 160°C for 30 minutes to prepare a vulcanized rubber sheet, which was then measured by the above test methods for the physical properties of the vulcanized rubber. The results are
35 shown in Table IV.

Table IV

	Stand. Ex. 4	Comp. Ex. 10	Ex. 13	Ex. 14
<u>Formulation (parts by weight)</u>				
SBR ^{*2}	80	80	80	80
NR ^{*3}	20	20	20	20
Silica ^{*1}	70	70	70	70
CB ^{*1}	10	10	10	10
6C ^{*1}	2	2	2	2
RD ^{*1}	2	2	2	2
Zinc White ^{*1}	2	2	2	2
Stearic acid ^{*1}	1	1	1	1
Oil ^{*1}	10	10	10	10
CZ ^{*1}	2.2	2.2	2.2	2.2
DPG ^{*1}	0.2	0.2	0.2	0.2
Sulfur ^{*1}	1.6	1.6	1.6	1.6
A-1289 ^{*1}	-	Treatment method 2	-	-
NXT ^{*1}	Treatment method 1	-	Treatment method 2	Treatment method 3
Bulk density retention rate (%)	38 to 160	78 to 84	96 to 98	97 to 99
<u>Evaluation of physical properties</u>				
Mooney viscosity (130°C)	100	90	65	64
Mooney viscosity (160°C)	100	87	74	72
Mooney viscosity (180°C)	100	98	75	74
Payne effect	100	106	60	59
Abrasion resistance	100	101	130	130
ΔE'	100	90	67	66
Low temperature wet skid performance	100	104	115	116

Notes to Table IV

*1: See notes to Table I

*2: Nipol 1502 made by Nippon Zeon

5 *3: Natural rubber (TSR20)

*4: See notes to Table II

Standard Example 4: 300 g of Nipsil AQ (Toso Silica Industry) was taken into a stainless steel bowl. 30 g of 3-octanoylthiopropyltriethoxysilane (NXT Silane) was
10 added, then a stainless steel spatula was used for stirring for 5 minutes. Part of the result was analyzed by the Soxhlet extraction method and elemental analysis

method. The same method as in Standard Example 2 was used to measure the range of the bulk density retention rate. It was confirmed to be 38 to 160%. (Treatment method 1)

5 Comparative Example 10: 30 g of NUCA-1289 silane made by Nippon Unicar was slowly added by a Henschel mixer into 300 g of Nipsil AQ (Toso Silica Industry), while stirring, to prepare dry surface-treated silica particles. The silane coupling agent surface-treated silica particles were dried in an explosion-proof oven
10 set to 150°C for 1 hour. The same method as in Standard Example 2 was used to measure the range of the bulk density retention rate. It was confirmed to be 78 to 84%. (Treatment method 2)

15 Example 13: 30 g of 3-octanoylthiopropyl-triethoxysilane (NXT Silane) was slowly added by a Henschel mixer into 300 g of Nipsil AQ (Toso Silica Industry), while stirring, to prepare dry surface treated silica particles. The silane coupling agent surface-treated silica particles were dried in an explosion-proof
20 oven set to 150°C for 1 hour. The same method as in Standard Example 2 was used to measure the range of the bulk density retention rate. It was confirmed to be 96 to 98%. (Treatment method 2)

25 Example 14: Except for not drying in an explosion-proof oven, the same procedure was followed as in Example 13 for treatment. The same method as with Standard Example 2 was used to measure the range of the bulk density retention rate. It was confirmed to be 97 to 99%. (Treatment method 3)

30 As explained above, in the prior art, in the silica-containing rubber composition, the silane coupling agent used is typically bis-3-triethoxysilylpropyltetrasulfide (A-1289), but this compound has two triethoxysilyl groups which serve as reaction sites with silica, so if the
35 treatment concentration is increased, the silane coupling agents will react with each other, the silica will aggregate, and the viscosity will rise. Further, it is

possible to use γ -mercaptopropyltrimethoxysilane having one trimethoxysilyl group and having one sulfur atom as the material, but a mercapto group is active, so scorching occurs during the mixture and the increase in the viscosity is caused. As opposed to this, according to the present invention, by blending in silica treated by 3-octanoylthiopropyltrialkoxysilane, preferably by a silane coupling agent treatment rate of 4 to 25%, it is possible to keep the Mooney viscosity of the rubber composition low. Further, in a conventional silane coupling agent (A-1289)-treated silica formulation, to keep the Mooney viscosity low, mixing at 140 to 165°C is necessary. Therefore, rubber scorching occurs due to the sulfur contained in the silane coupling agent, or the polymer radicals formed by molecular cleavage react and gelation occurs. As opposed to this, the rubber composition containing silica pretreated by 3-octanoylthiopropyltri-alkoxysilane according to the present invention has an extremely small dependency of the Mooney viscosity on the mixing temperature, a smaller variation in Mooney viscosity due to mixing, and the capability to be mixed at a temperature of about 120 to 130°C, and, therefore, no rubber scorching due to the sulfur contained in the silane coupling agent occurs and the polymer radicals formed by molecular cleavage do not react and, therefore, excessive gelation can be suppressed. Further, when using an ordinary mono- or disulfide-type silane coupling agent, the reinforcing capability of the rubber is decreased, compared with the case of using tetrasulfide type A-1289, and, therefore, with the system including silica pretreated by 3-octanoylthiopropyltrialkoxysilane of the present invention, there is a reinforcing capability equal to the A-1289 or more.

Standard Example 5, Examples 15 to 19, and Comparative Examples 11 to 14

Preparation of Samples

In each of the formulations shown in Table V, the ingredients other than the vulcanization accelerator and sulfur were mixed by a 3 liter internal mixer and discharged, when reaching $145 \pm 5^\circ\text{C}$, to obtain a master batch. This master batch then had the vulcanization accelerator and sulfur mixed thereinto by an open roll to obtain a rubber composition. This rubber composition was used and evaluated by the above test method for the unvulcanized physical properties. The results are shown in Table V.

Next, each rubber composition thus obtained was vulcanized in a $15 \times 15 \times 0.2$ cm mold at 160°C for 30 minutes to prepare a vulcanized rubber sheet which was then measured by the above test methods for the physical properties of the vulcanized rubber. The results are shown in Table V.

Test Methods for Evaluation of Rubber Physical Properties

Mooney viscosity (ML_{1+4}): Measured based on JIS K-6300 mixed at 120°C and 135°C .

Abrasion resistance: A Lambourn abrasion tester was used to measure the volume of abrasion loss under conditions of a temperature of 23°C /slip rate 50%. The obtained results are shown indexed against the value of Standard Example 5. The larger this numeral value, the better the abrasion resistance shown.

$\Delta E'$ (change of -50°C to 0°C): E' at -50°C and 0° (stored elasticity) measured based on JIS K-6394 under conditions of frequency 20 Hz/initial strain 10%/strain amplitude 2%. The smaller the difference of E' at -50°C and 0°C , the smaller the E' temperature dependency.

Change of hardness due to aging: Hardness before and after aging ($80^\circ\text{C} \times 96$ hours) (measured based on JIS K-6200 at 80°C) with the value of the ratio (after aging/before aging) indexed to the value of Standard

Example 5. The smaller this value, the smaller the change in hardness due to aging.

Frictional force on ice: Frictional coefficient on ice measured by an inside drum type ice friction tester.

- 5 The measurement temperature was made -1.5°C and -5°C . The results are indexed to the value of Standard Example 5. The larger the value, the higher the frictional force on ice shown.

Table V

	Stand. Ex. 5	Comp. Example					Example				
		11	12	13	14	15	16	17	18	19	
<u>Formulation (parts by weight)</u>											
NR	60	60	60	60	60	60	60	60	60	60	
BR	40	40	40	40	40	40	40	40	40	40	
Silica	20	20	20	-	-	-	-	-	-	-	
A-1289	1.6	-	-	-	-	-	-	-	-	-	
A-1589	-	1.6	-	-	-	-	-	-	-	-	
NXT	-	-	2.2	-	-	-	-	-	-	-	
A-1289 treated silica (8% ^{*1}) (75 to 82% ^{*3})	-	-	-	21.6	-	-	-	-	-	-	
A-1589 treated silica (8% ^{*1}) (85 to 90% ^{*3})	-	-	-	-	21.6	-	-	-	-	-	
NXT treated silica (5% ^{*2}) (95 to 99% ^{*3})	-	-	-	-	-	21.0	-	-	-	-	
NXT treated silica (11% ^{*2}) (96 to 98% ^{*3})	-	-	-	-	-	-	22.2	-	-	-	
NXT treated silica (20% ^{*2}) (75 to 82% ^{*3})	-	-	-	-	-	-	-	24	-	-	
NXT treated silica (2% ^{*2}) (95 to 98% ^{*3})	-	-	-	-	-	-	-	-	-	-	
NXT treated silica (30% ^{*2}) (90 to 105% ^{*3})	-	-	-	-	-	20.4	-	-	-	26	
CB	40	40	40	40	40	40	40	40	40	40	
6C	2	2	2	2	2	2	2	2	2	2	
Zinc White	3	3	3	3	3	3	3	3	3	3	
Stearic acid	1	1	1	1	1	1	1	1	1	1	
Oil	30	30	30	30	30	30	30	30	30	30	
CZ	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	
Sulfur	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	
<u>Evaluation of physical properties</u>											
Mooney viscosity (120°C)	100	103	110	90	91	80	75	65	60	85	
Mooney viscosity (135°C)	100	105	105	87	85	85	80	74	70	90	
Abrasion resistance	100	87	97	98	91	102	112	127	117	110	
ΔE' (change of -50°C to 0°C)	100	92	87	94	95	87	86	83	80	81	
Change of hardness due to aging (80°C x 96 hr)	100	96	97	100	100	97	96	90	89	97	
Frictional force on ice (-1.5°C)	100	93	98	103	95	105	110	115	112	103	
Frictional force on ice (-5°C)	100	95	101	105	97	115	122	135	129	108	

*1: Silane coupling agent treatment rate by A-1289 or A-1589

*2: Silane coupling agent treatment rate by NXT

*3: Bulk density retention rate

Notes to Table V

NR: Natural rubber (TSR20)

BR: Nipol BR 1220 made by Nippon Zeon

Silica: Nipsil AQ made by Toso Silica Industry

5 A-1289: Bis(3-triethoxysilylpropyl)tetrasulfane made by Nippon Unicar

A-1589: Bis(3-triethoxysilylpropyl)disulfane made by Nippon Unicar

10 NXT: 3-octanoylthiopropyltriethoxysilane (NXT Silane) made by Nippon Unicar

A-1289 surface-treated silica and A-1589 surface treated silica: Nippon Unicar NUCA-1289 silane or NUCA-1589 was slowly added in Henschel mixer into Nipsil AQ (Toso Silica Industry) while stirring to prepare dry reaction
15 silica particles. The silane coupling agent reaction silica particles were dried in an explosion-proof oven set to 150°C for 1 hour.

NXT treated silica: The above NXT was slowly added by a Henschel mixer into Nipsil AQ (Toso Silica Industry)
20 while stirring to prepare dry reaction silica particles. The silane coupling agent reaction silica particles were dried in an explosion-proof oven set to 150°C for 1 hour. Note that the bulk density retention rate was found in the above way. The results are shown in Table V.

25 CB: Shoblack N339 made by Showa Cabot

6C: Santoflex 6PPD made by Flexsys

Zinc White: Ginrei R made by Toa Zinc

Stearic acid: Beads Stearic Acid YR made by NOF Corporation

30 Oil: Process X-140 made by Japan Energy

CZ: Noccelar CZ-G made by Ouchi Shinko Chemical Industrial

Sulfur: Oil extended sulfur made by Karuizawa Refinery (oil content 5%)

35 As is clear from the results shown in Table V, in Examples 15 to 19, compared with Standard Example 5, the decrease in the Mooney viscosity is large and the

abrasion resistance, $\Delta E'$, the change in hardness due to aging, and frictional force on ice are improved. As opposed to this, in Comparative Examples 11 and 12, A-1589 and 3-octanoylthiopropyltriethoxysilane (NXT silane) were charged into solutions, so compared with the A-1289 formulation, the Mooney viscosity is high. In Comparative Examples 13 and 14, silica reacted with A-1289 and A-1589 is included, so compared with the charging of A-1289 and A-1589 alone, the decrease in the viscosity is large and, compared with Comparative Examples 11 and 12, the abrasion resistance and frictional force on ice are improved, but even so the levels of Examples 15 to 19 are not achieved.

INDUSTRIAL APPLICABILITY

As explained above, the silica-containing rubber composition according to the present invention can improve the abrasion resistance, wet skid performance, etc., without detracting from the reinforcing action and, for example, is suitable for use for a passenger car tread rubber, in particular a passenger car tread rubber designed for markets of low usage temperature regions etc. Further, the rubber composition according to the second aspect of the present invention is superior in processability, small in temperature dependency of E' (stored elasticity) at the time of a low temperature (-50°C to 0°C), superior in frictional force on ice and abrasion resistance, and small in change of hardness due to aging, and, therefore, is useful, as a rubber composition for a studless tire.